# Probing the far infrared in support of ESA's Far infrared Outgoing Radiation Understanding and Monitoring (FORUM) mission

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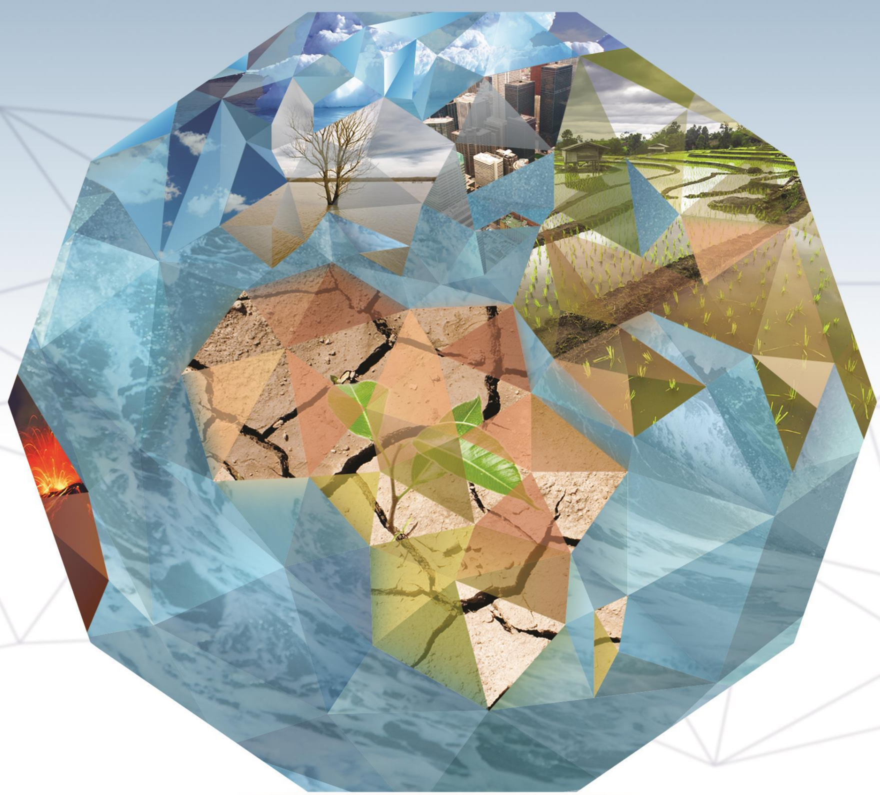
# What is FORUM?

## ESA Earth Explorer 9 Candidate Mission



- Earth Explorer (EE) missions: science and research element of ESA's Living Planet Programme
- Focus on atmosphere, biosphere, hydrosphere, cryosphere and Earth's interior
- Increasing emphasis on the Earth system as a whole and anthropogenic impact on natural Earth processes
- Core or Opportunity class
- EE5 (AEOLUS) launched 22nd August: providing first data

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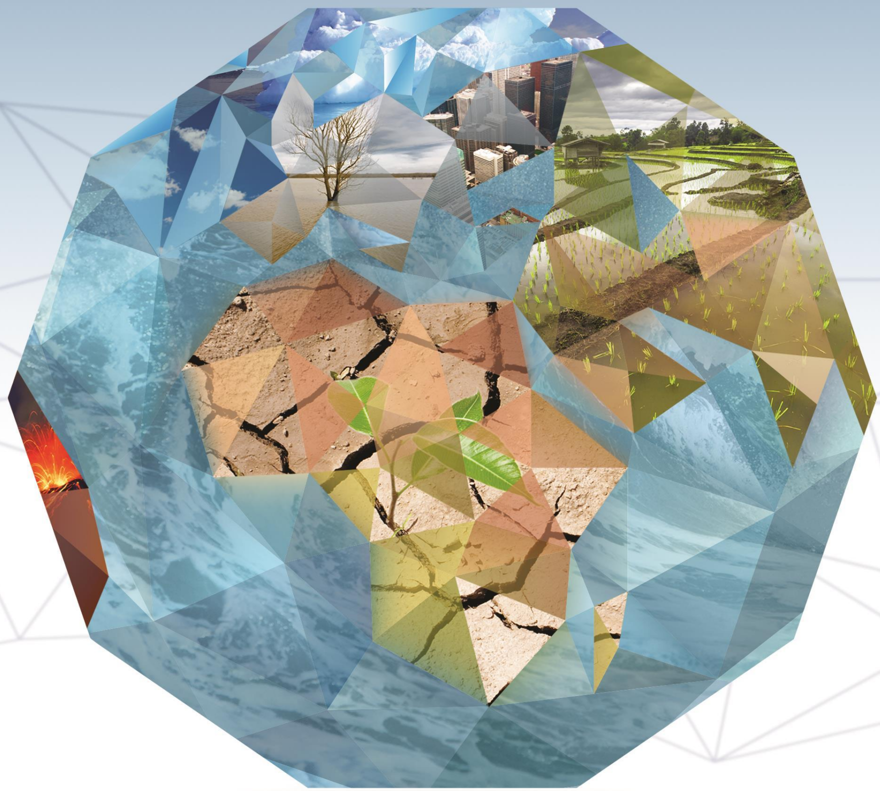

- EE9 – 13 proposals (June 2017)
- Down-selected to 2 (Nov. 2017) for ‘two-year’ Phase A study
- SKIM (Sea-surface Kinematics Multiscale monitoring)
- FORUM (Far infrared Outgoing Radiation and Monitoring)

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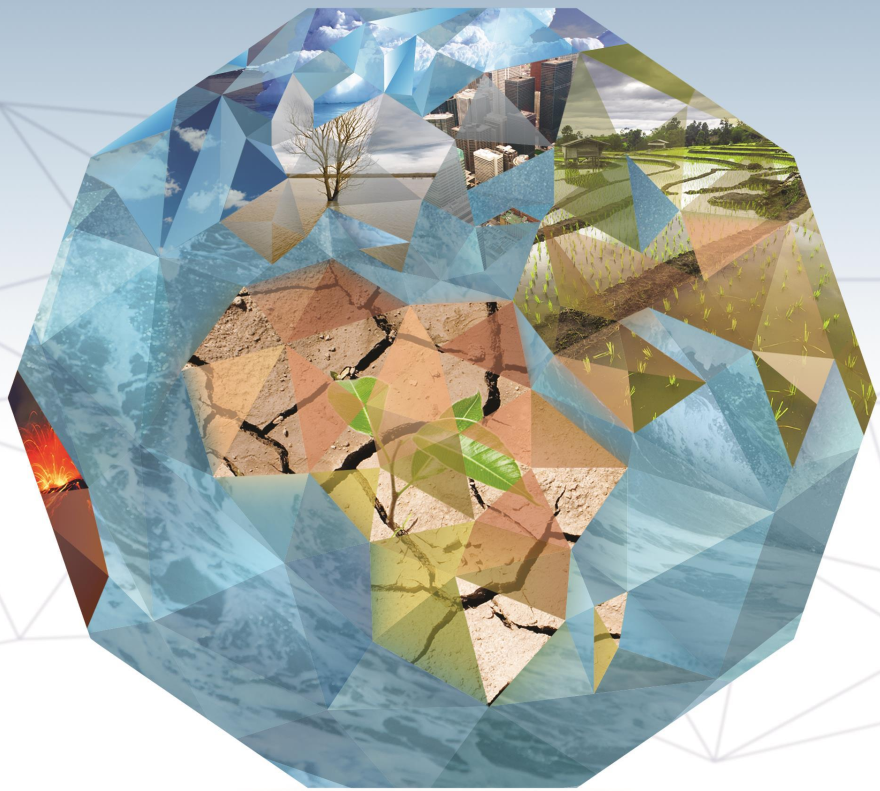

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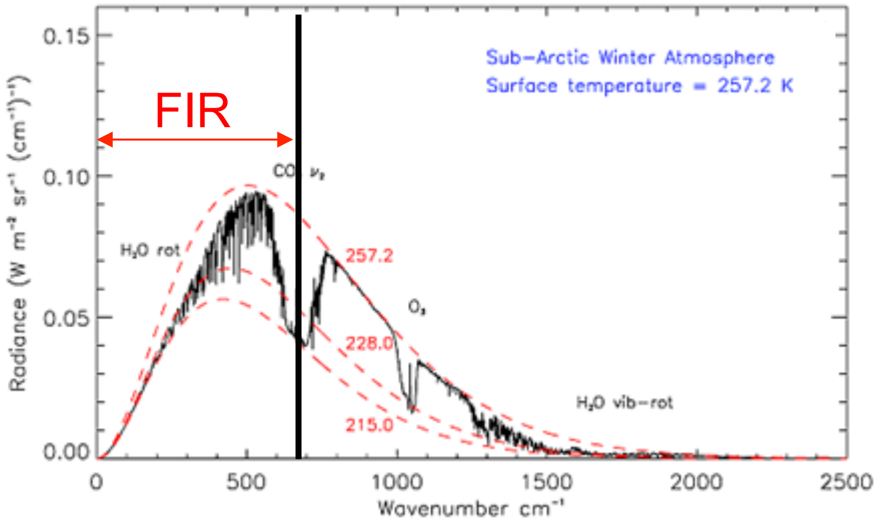
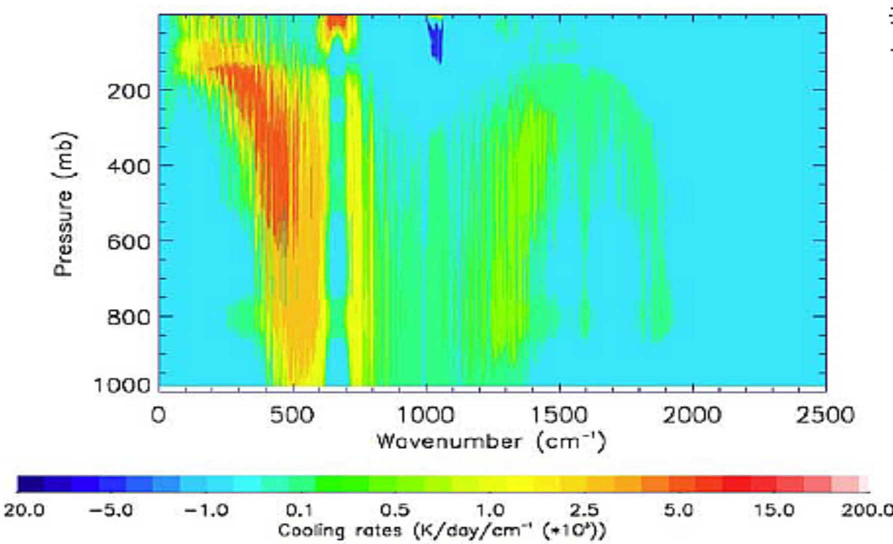
- SKIM (Sea-surface Kinematics Multiscale monitoring)
- **FORUM (Far infrared Outgoing Radiation and Monitoring)**

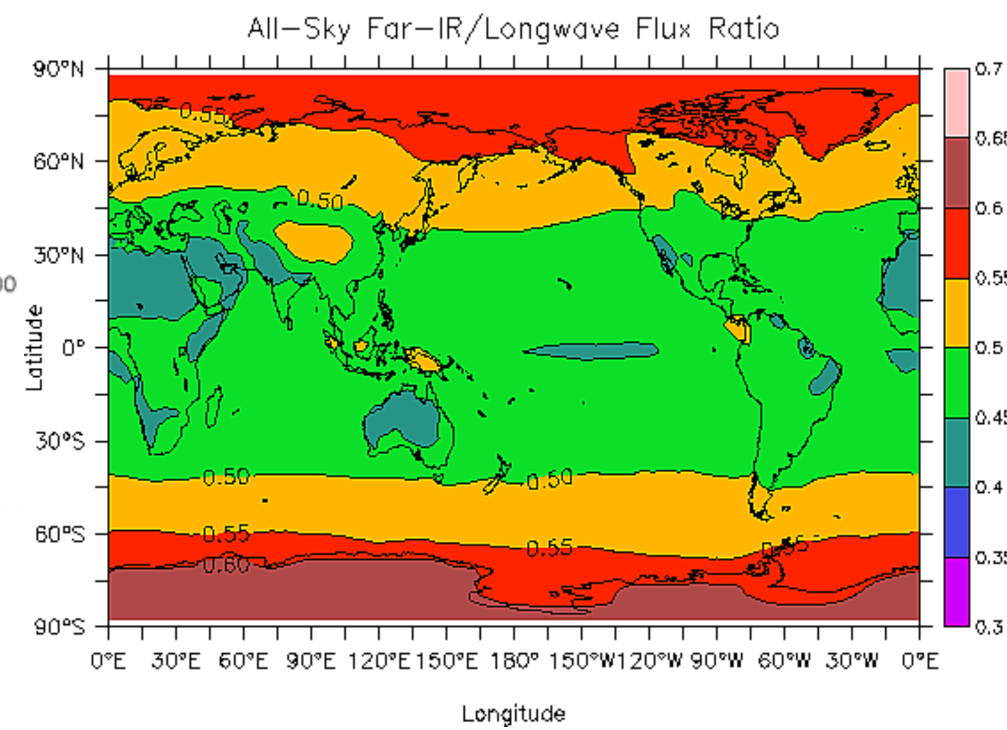
Goal: First ever measurement of entire (far)-infrared spectrum from space, with high radiometric accuracy

# Why FORUM?




Simulated clear-sky OLR for sub-Arctic winter and associated cooling rates (Brindley and Harries, 1998, Harries *et al*., 2008)



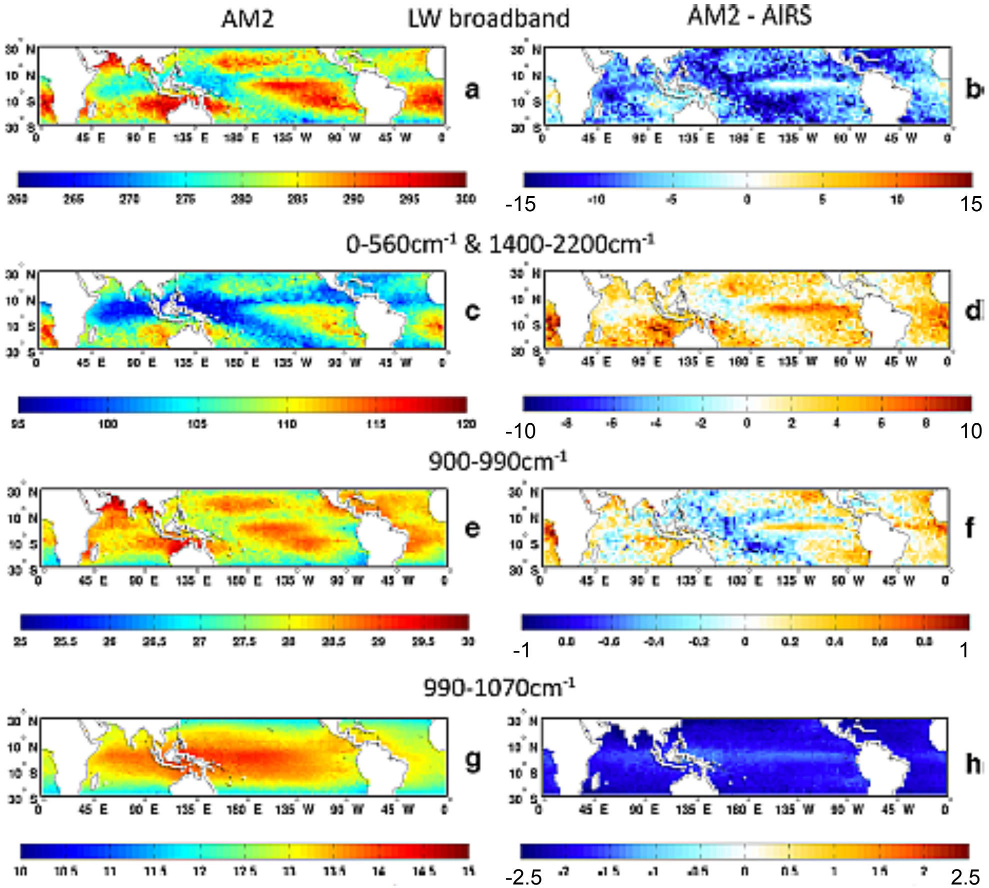




Simulated fraction of all-sky OLR within the far infrared (after Mlynczak and Collins, 2001)

# Why FORUM?

But we can measure broadband OLR so why do we care?

(I) Model evaluation: diagnosis of gross biases and compensation effects; processes




Simulated clear-sky OLR (left column) and difference with AIRS estimates (right column) for different spectral bands. (Brindley and Bangtes, 2016, adapted from Huang et al., 2008)

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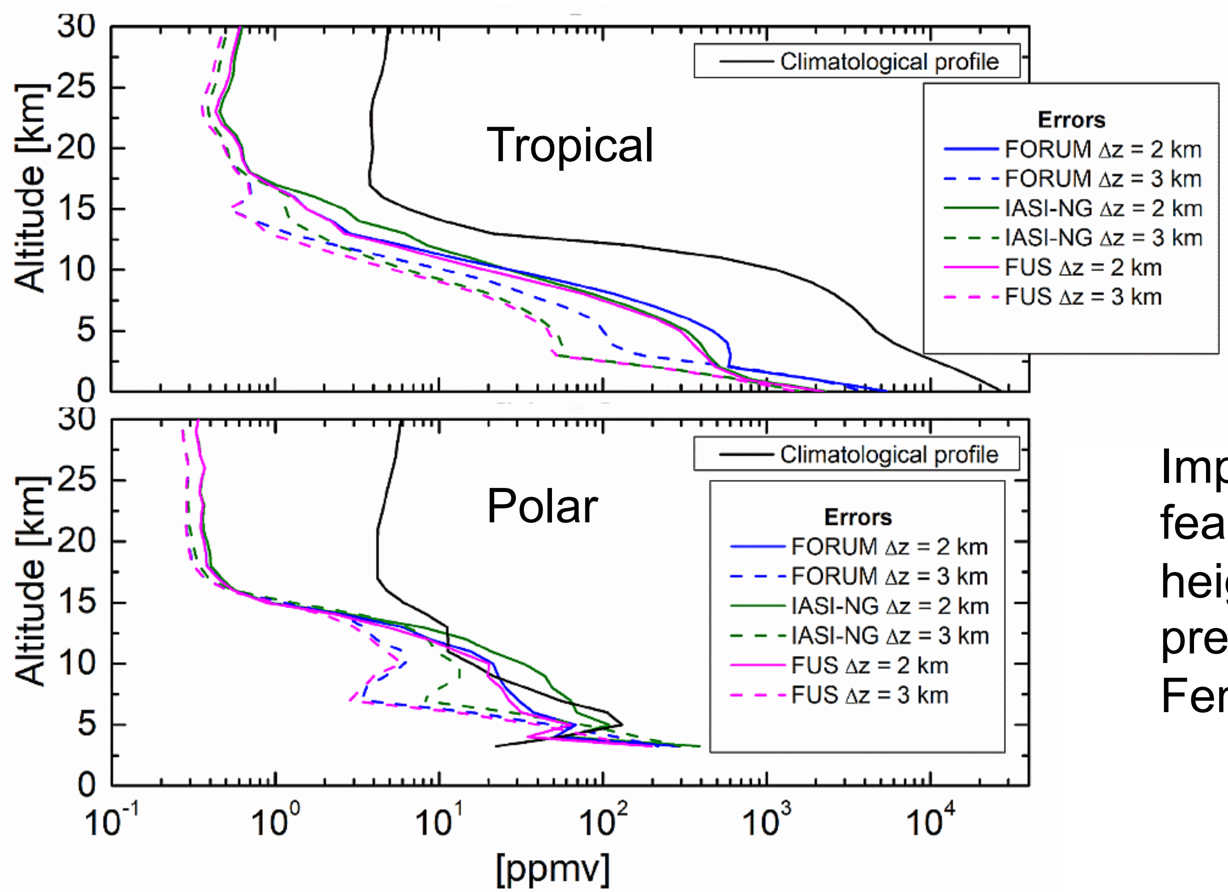
# Why FORUM?

(II) Improved retrievals of key geophysical parameters for climate sensitivity

(A) Upper tropospheric/Lower stratospheric water vapour




In agreement with Merrelli and Turner (2012)

Improved retrievals also feasible above cloud top height (e.g. in the presence of anvil cirrus, Feng and Huang, 2018)

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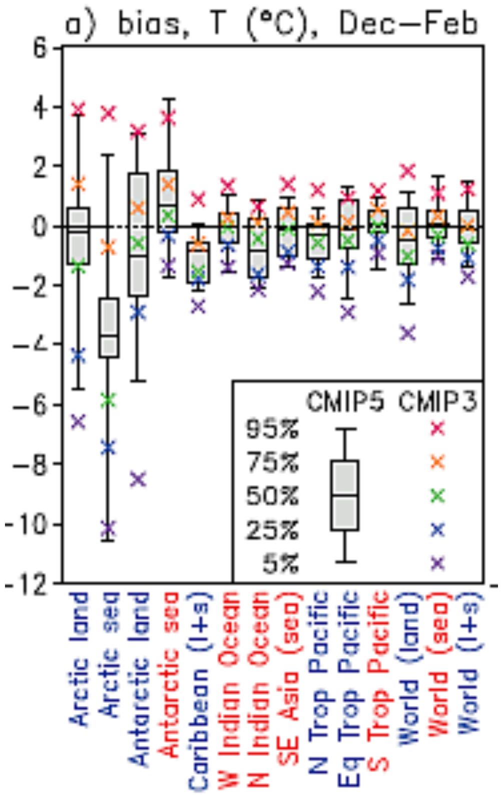
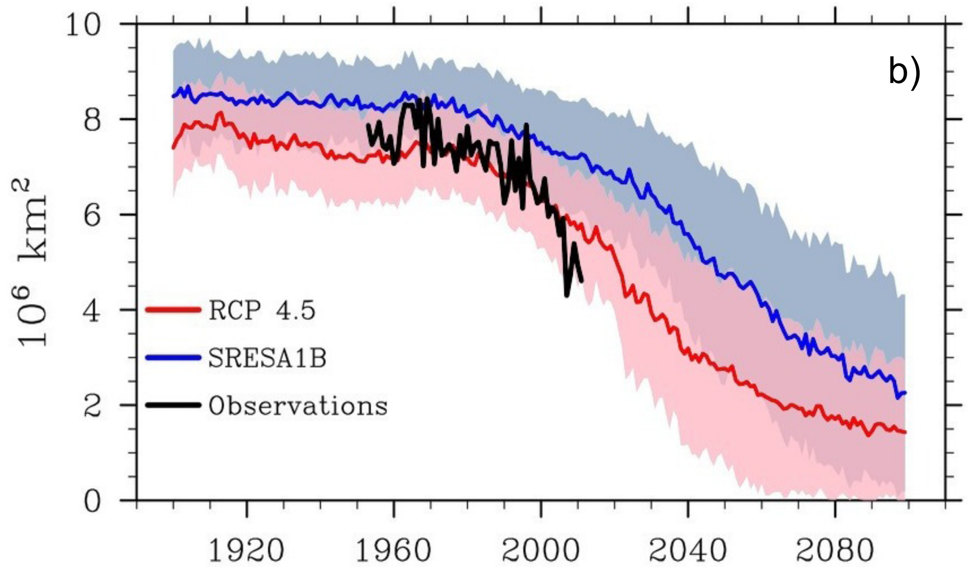
# Why FORUM?

(II) Improved retrievals of key geophysical parameters for climate sensitivity

(B) High-latitude surface emissivity

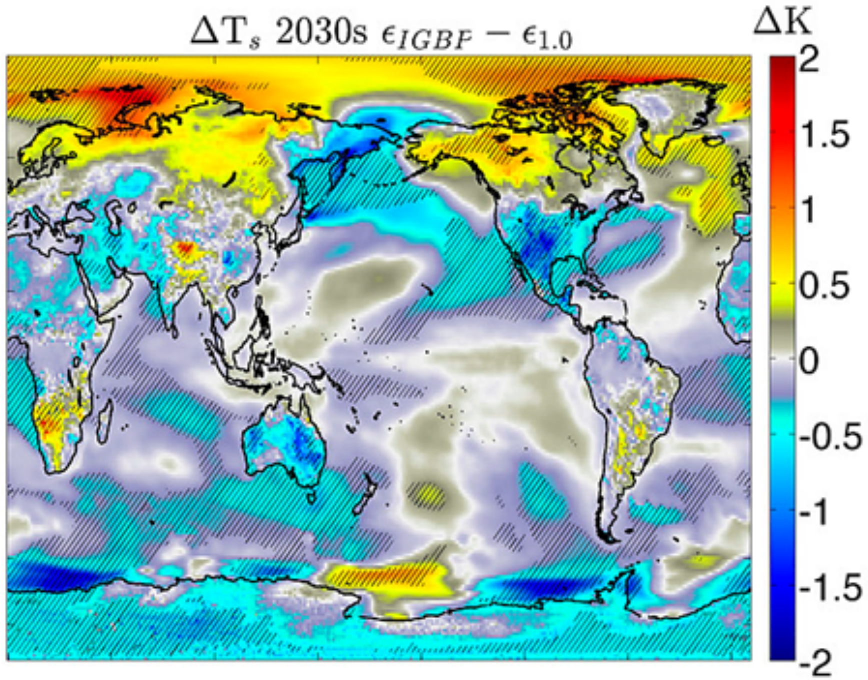


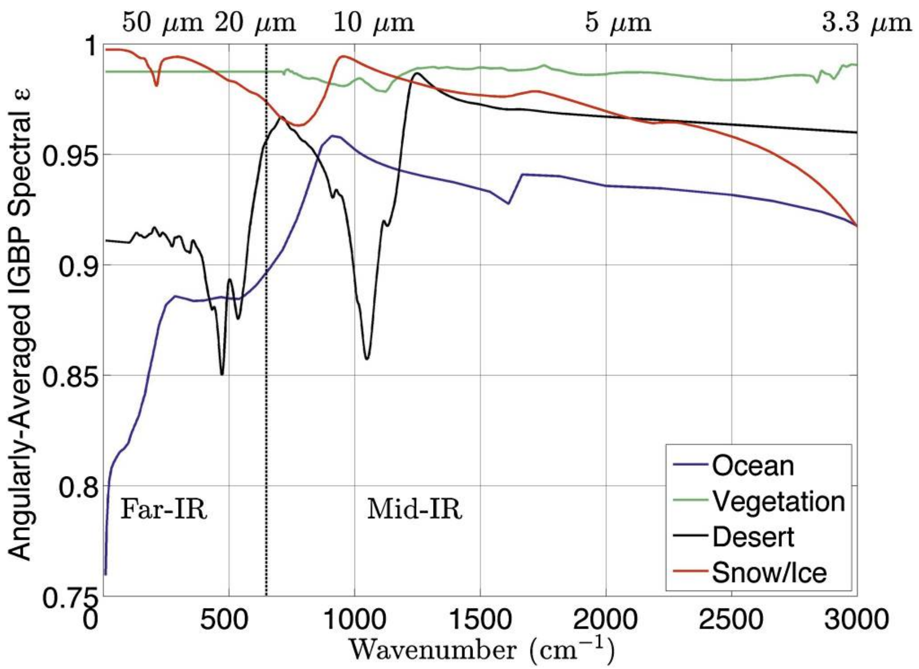

(a) Dec-Feb multi-model temperature biases relative to ERA-I from 1986-2005 (Flato et al., IPCC, 2013)




(b) Observed September sea-ice extent from 1952-2010 (black) and from 1900-2100 under BaU scenario (CMIP3 models – blue) and RCP 4.5 scenario (CMIP5 models – red). (from Stroeve et al., 2012)

# Why FORUM?




- Implementing estimates of spectral snow/ice surface emissivity reduces temperature bias in CESM (Kuo *et al*., 2018)
- Role of emitted far infra-red radiation seems important in determining future Arctic change (Feldman *et al*., 2014 but see also Huang *et al*., 2018)
- Caveat: All studies use theoretical FIR surface emissivities

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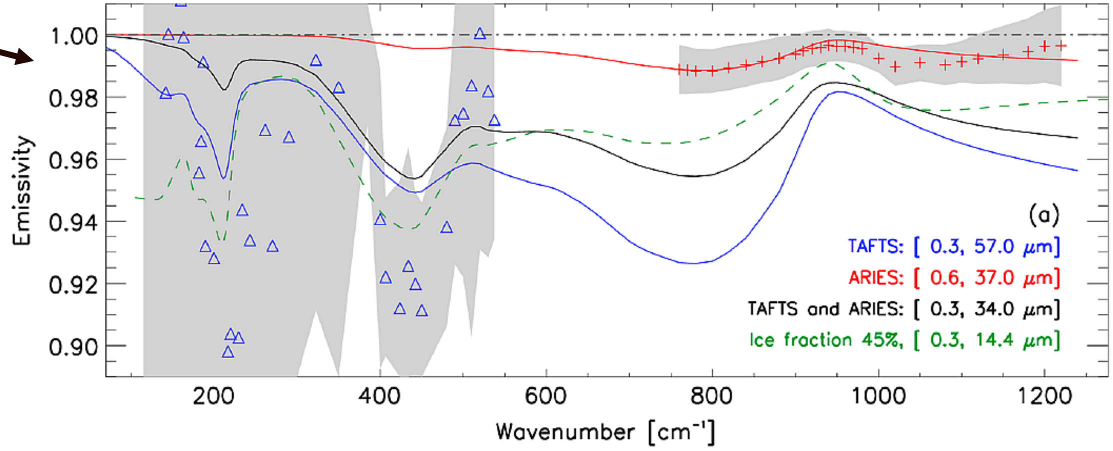
# CIRCCREX/COSMICS Campaign

- NERC CIRrus Coupled Cloud-Radiation EXperiment / Cold-air Outbreak and Sub-Millimetre Ice Cloud Study

- Using the Faculty for Atmospheric Airborne Measurements (FAAM)

- Focus on flight B898 (19th March 2015). Low level run (300 m agl) already successfully exploited (Bellisario *et al*., 2017)

- Can high level runs in the UTLS provide similar information given the longer atmospheric path length?



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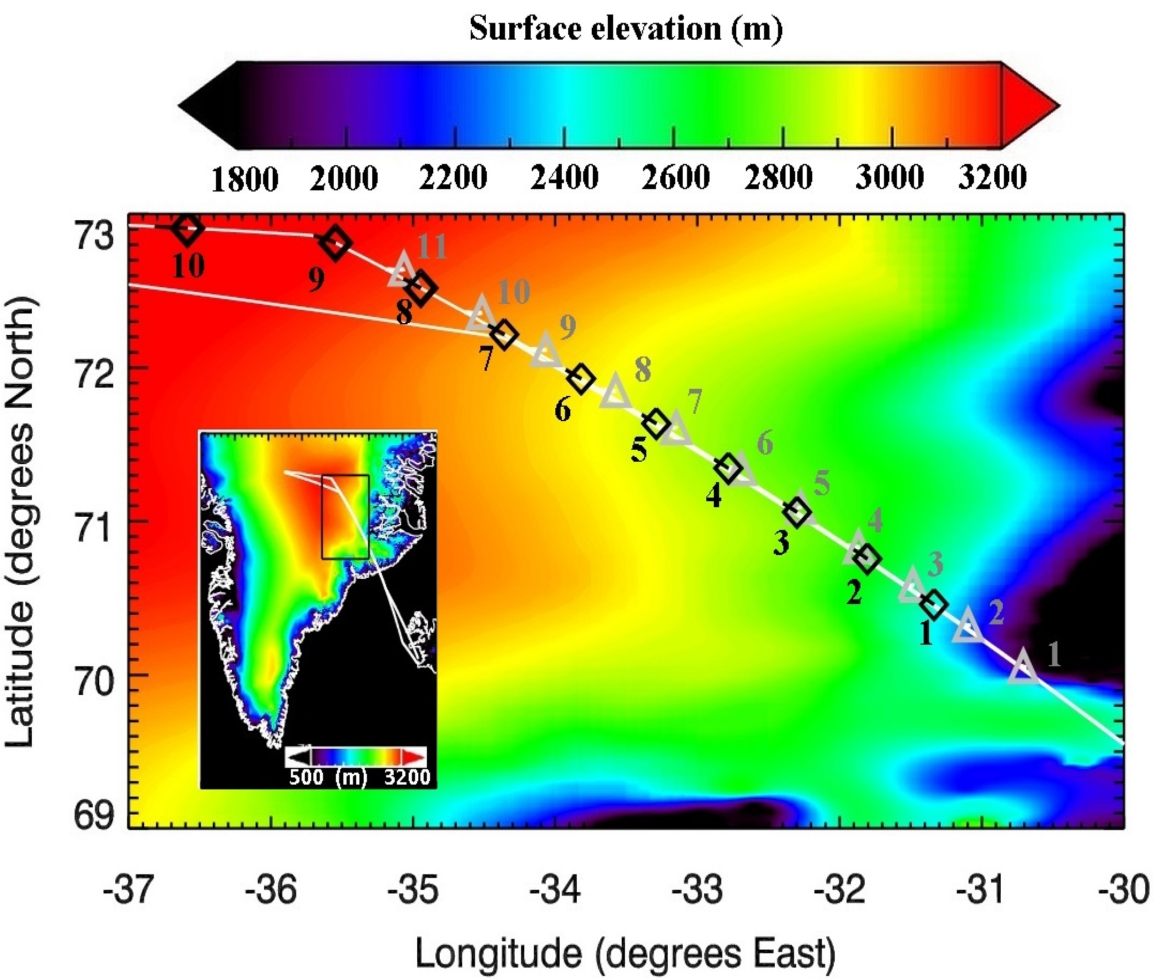
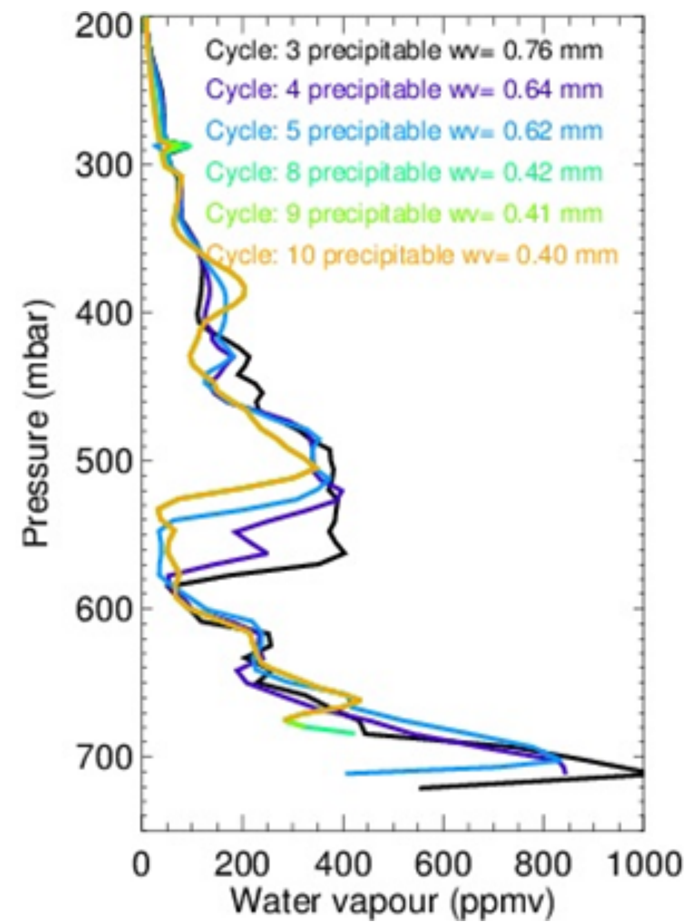
# B898 Flight Track and atmospheric conditions




Typically low water content, clear-sky. Temperature profile is relatively constant with space/time.

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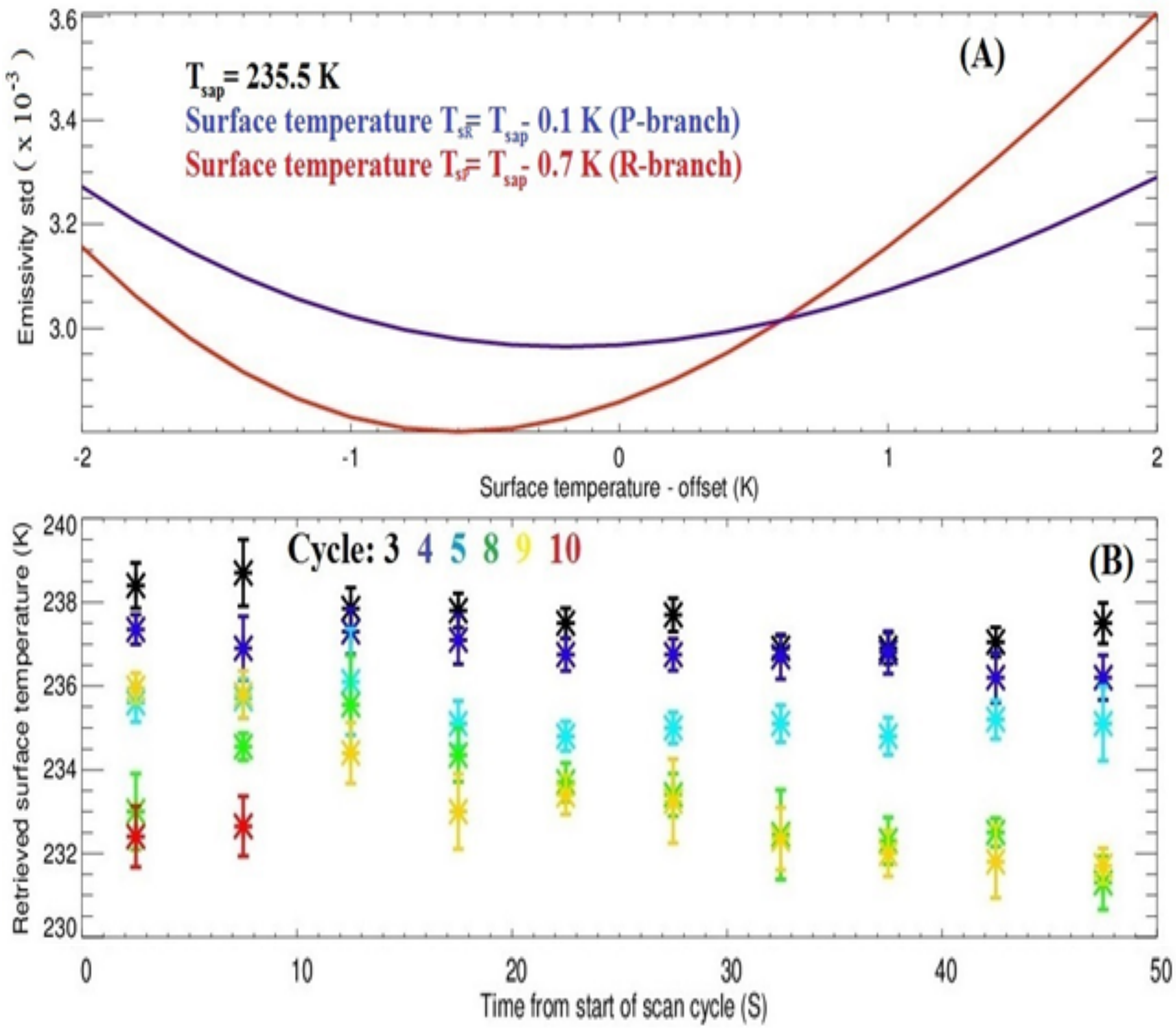
# Estimating surface temperature

- Makes use of Mid-IR radiances from the Airborne Research Interferometer Evaluaton System (ARIES)
- Iteratively solves RTE in two micro-windows from 930-960 and 960-990 $cm^{-1}$ and finds $T_s$ which minimises spectral variation in $\varepsilon_s$ (e.g. Knuteson et al., 2004)
- Combines values from both windows and variability within scan to assess uncertainty in $T_s$ retrieval



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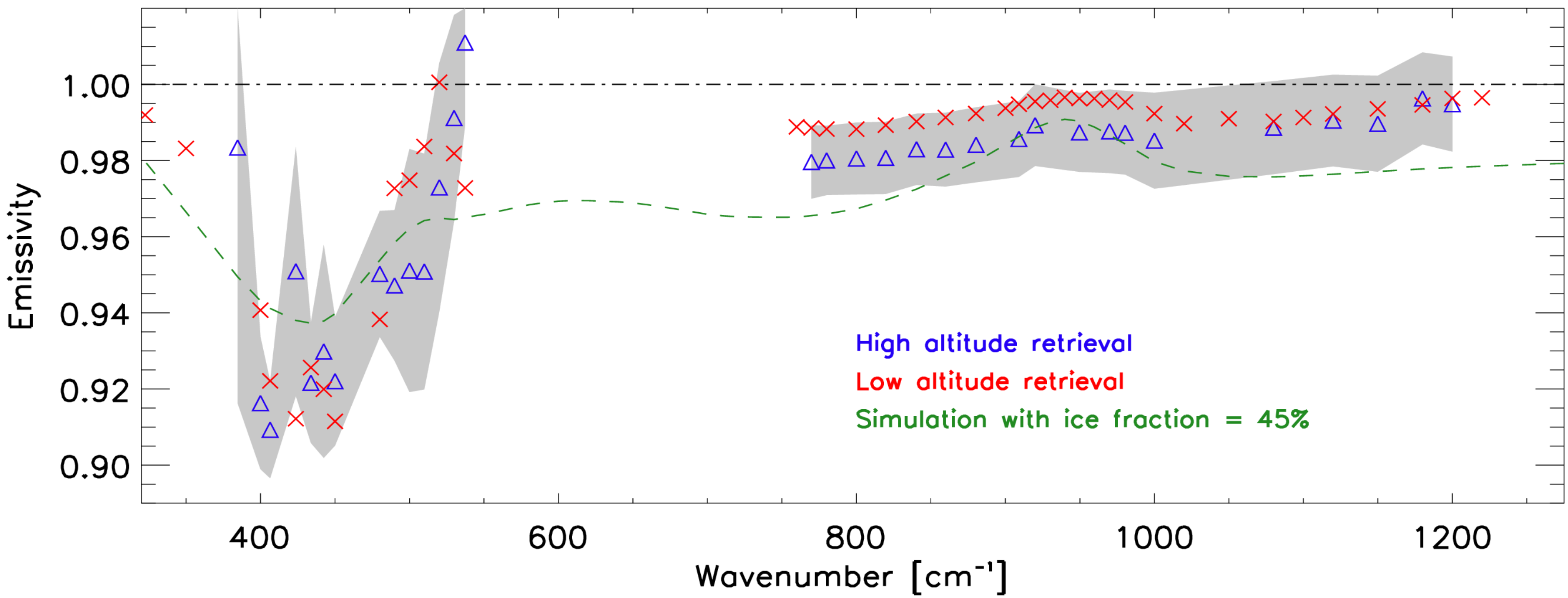
# Final Retrievals




- Cycle 10: closest in time and location to the low level measurements.
- Cycles nearer the coast show spectrally flatter behaviour in the FIR, with higher emissivities across the infrared as a whole. To first order the behaviour is consistent with a reduction in snow grain size as one moves towards the interior of the plateau.

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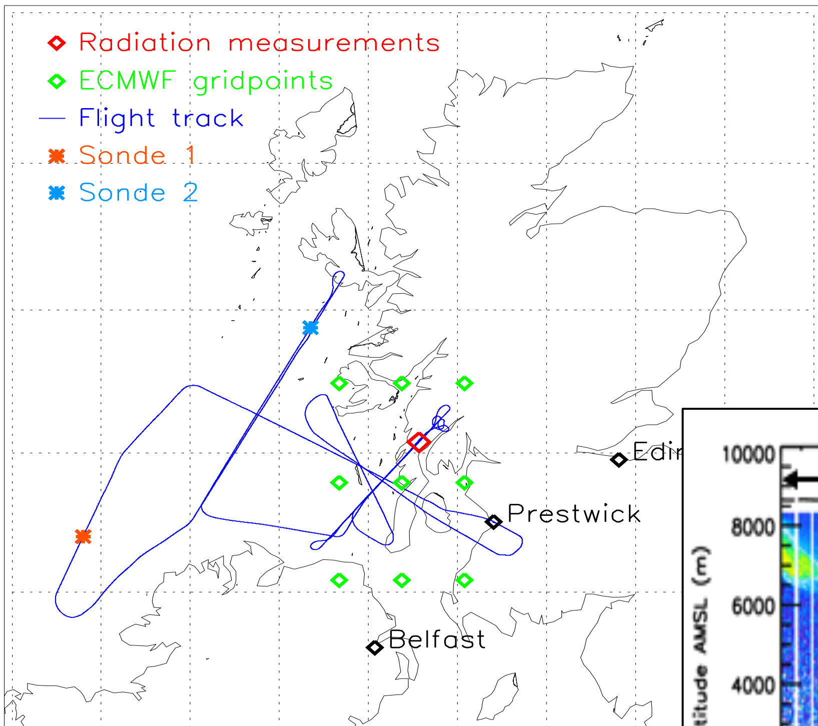
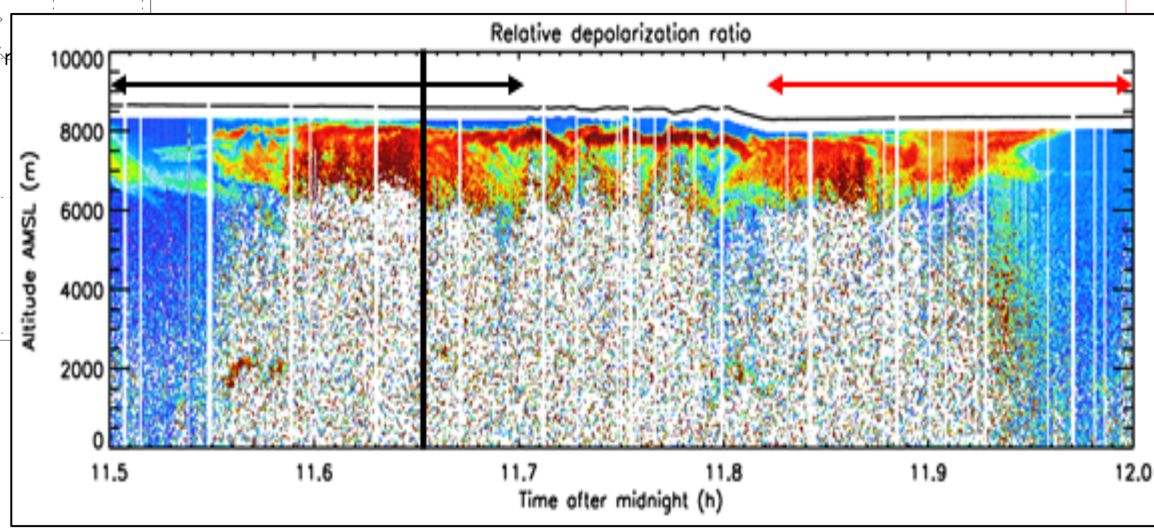
(II) Improved retrievals of key geophysical parameters for climate sensitivity

(C) Cirrus (and mixed phase) cloud




CIRCCREX Flight B818
29th November 2013



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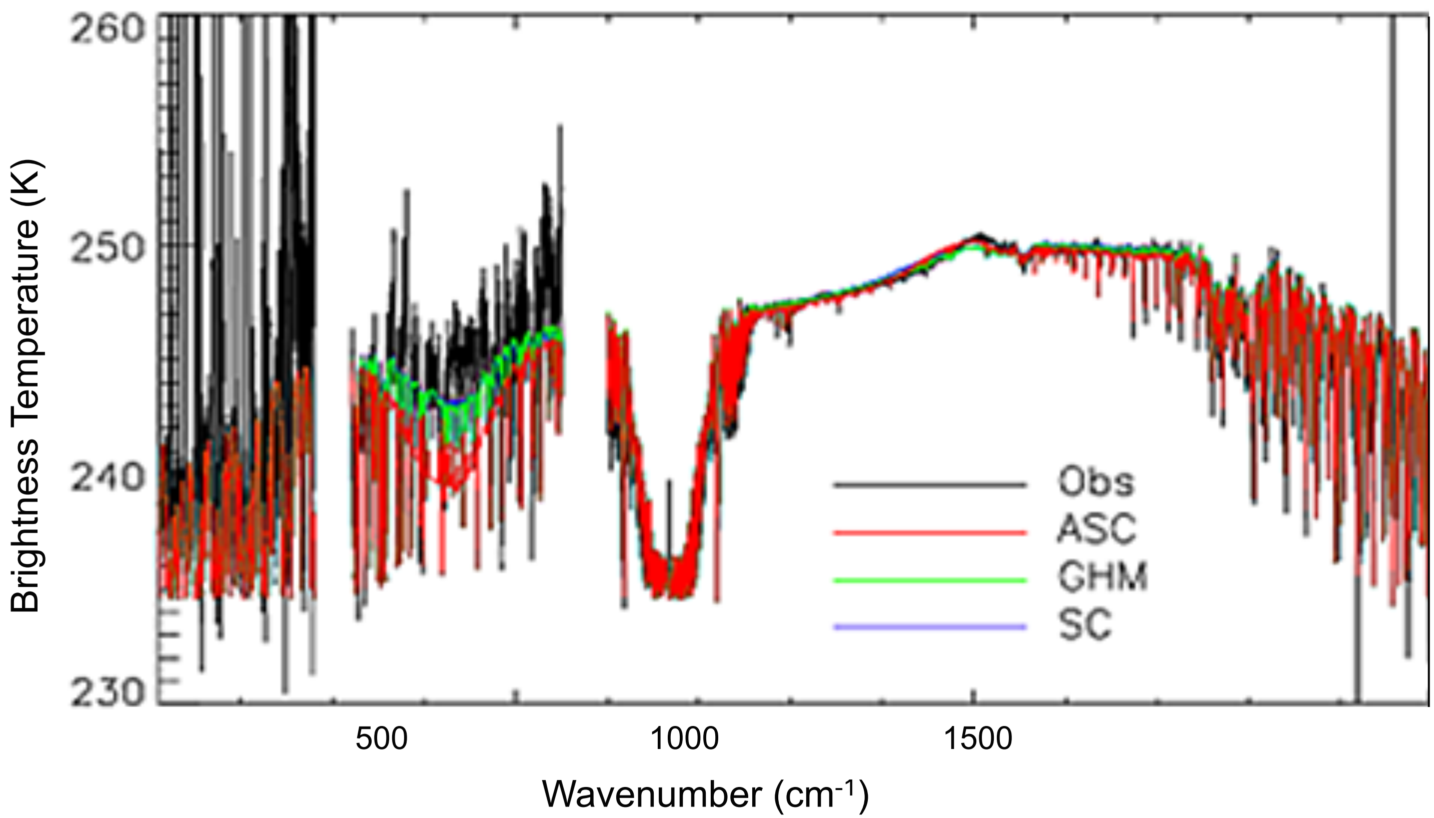

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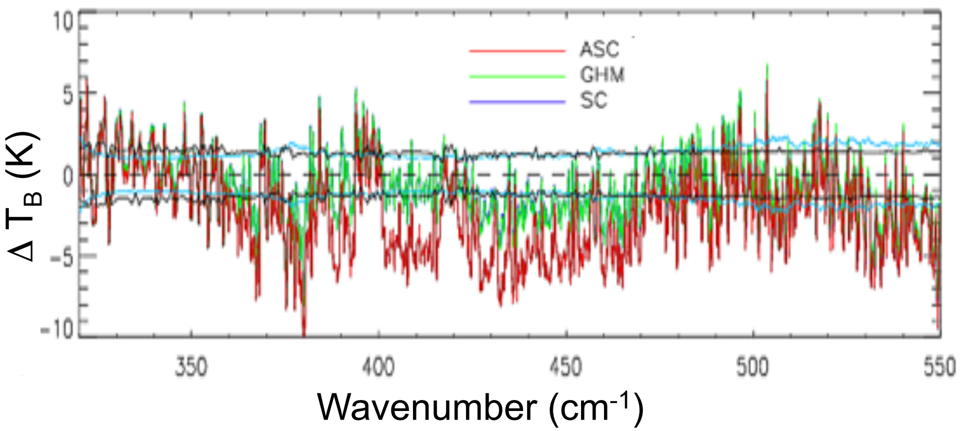
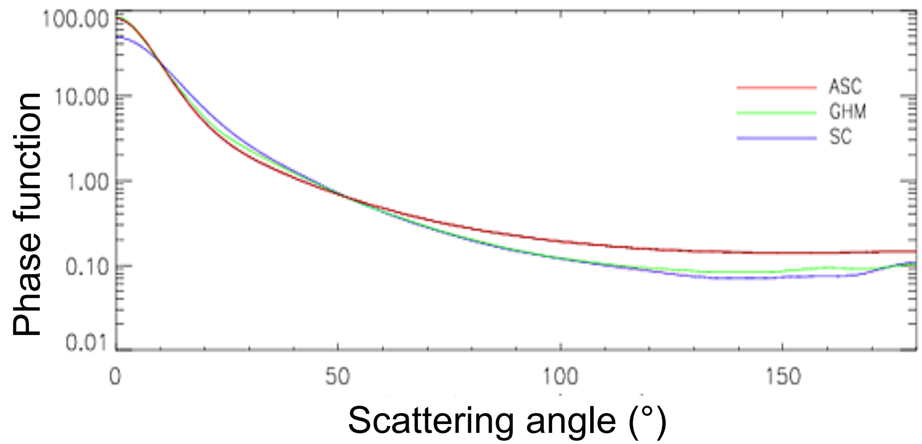
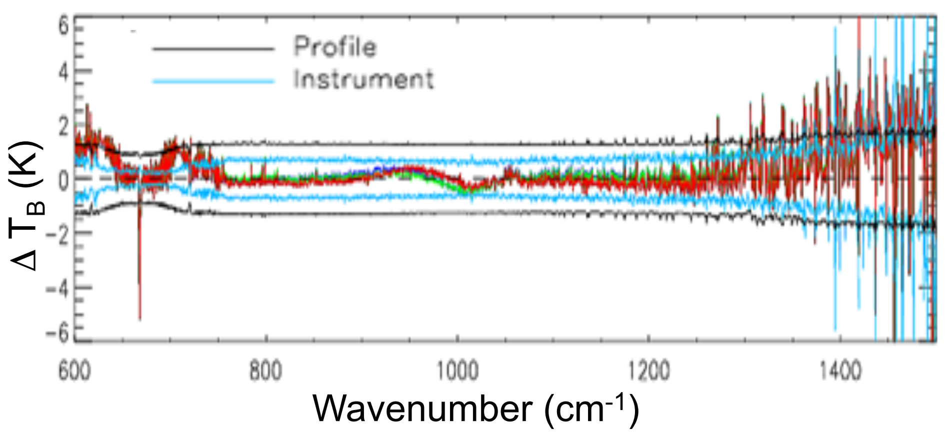
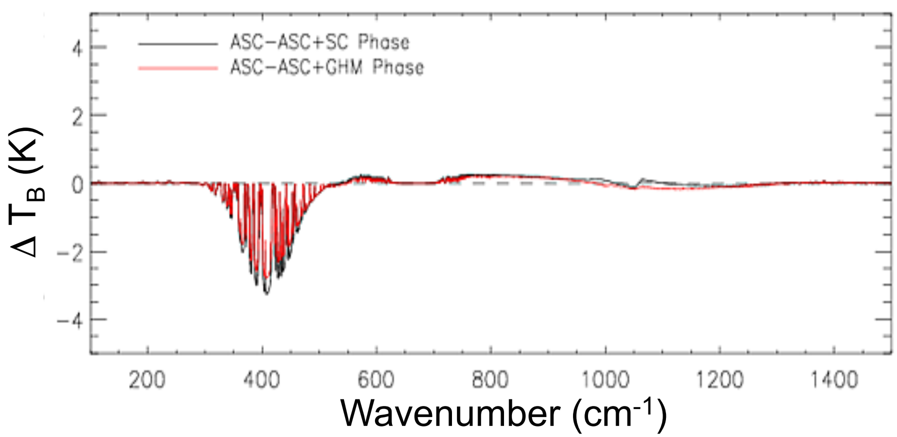


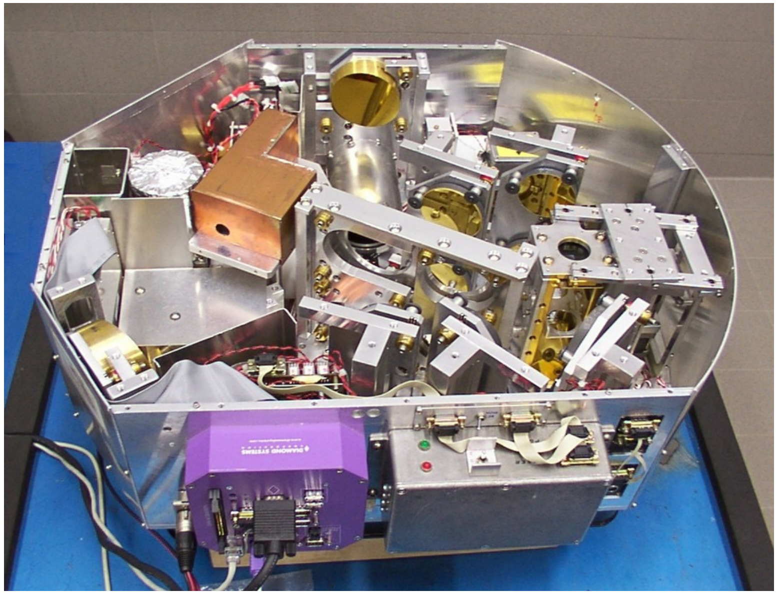



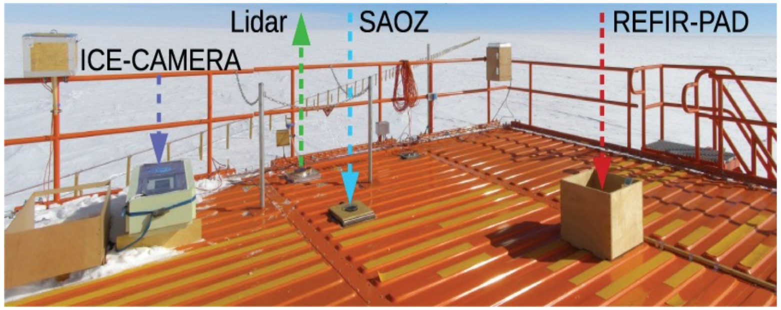
# FORUM payload

FORUM Fourier Transform Spectrometer (FSI) and FORUM Embedded Imager (FEI)

FSI (FORUM Sounding Instrument)
Builds on heritage of REFIR-PAD (Carli et al, 1999) – acquiring data autonomously in Antarctica since 2011 (Palchetti *et al*., 2013) from 100-1400 $cm^{-1}$ at 0.5 $cm^{-1}$ resolution

FEI (FORUM Embedded Imager)
Narrow-band imager for cloud detection





# Instrument specifications (TBC)

FSI

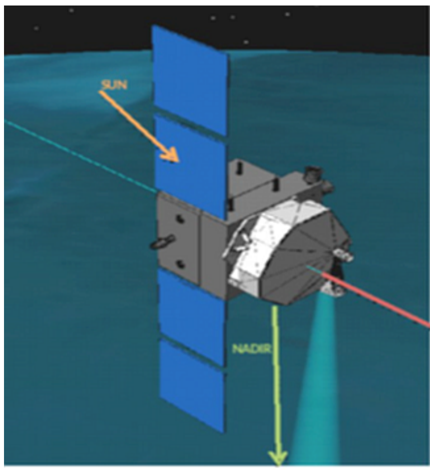
| Parameter | Requirement |
|---|---|
| Spectral range | 100-1600 $cm^{-1}$ |
| Spectral resolution | <0.36 $cm^{-1}$ |
| Ground pixel diameter | 12 km |
| Along track sampling | <70 km |
| Radiometric absolute accuracy | 0.1 K (300-1600 $cm^{-1}$)<br>0.2 K (100-300 $cm^{-1}$)<br>(190-300 K) |
| NESR (100-200 $cm^{-1}$) | 1 mW $m^{-2}$ $sr^{-1}$ $cm^{-1}$ |
| NESR (200-800 $cm^{-1}$) | 0.4 mW $m^{-2}$ $sr^{-1}$ $cm^{-1}$ |
| NESR (800-1600 $cm^{-1}$) | 1 mW $m^{-2}$ $sr^{-1}$ $cm^{-1}$ |

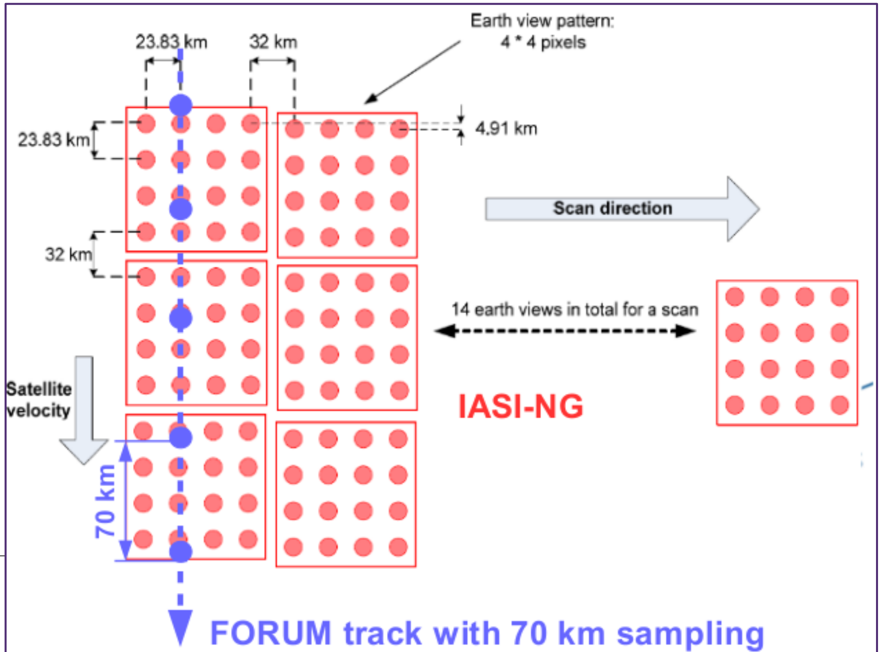
FEI

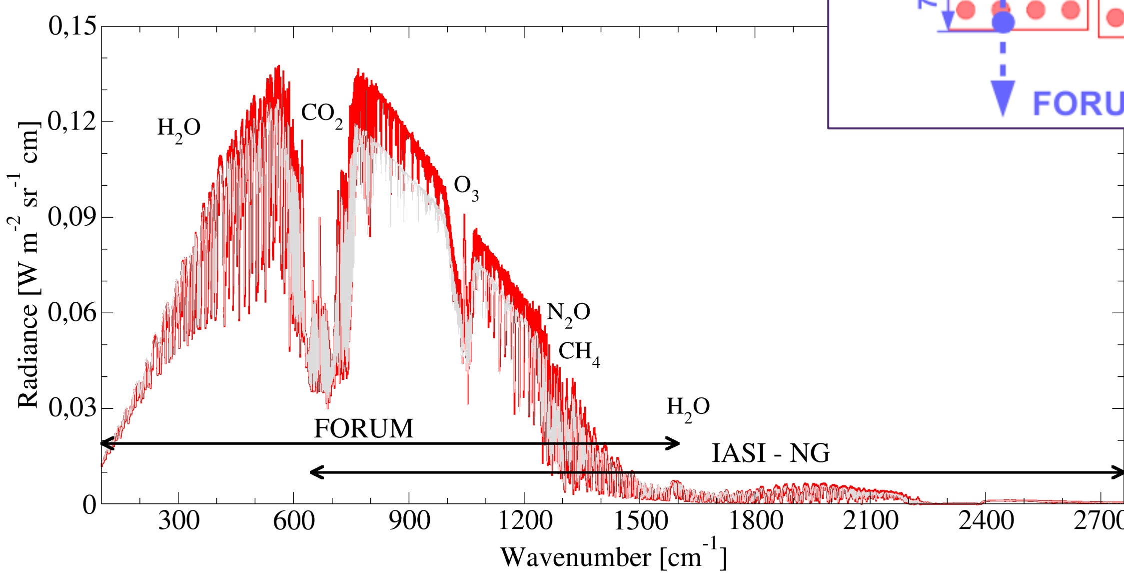
| Parameter | Requirement |
|---|---|
| Channel central $\lambda$ (width) | 11.5 $\mu$m (2 $\mu$m) |
| Measurement freq | <5/FSI dwell time |
| Spatial res (1 pixel) | 0.6 km |
| Footprint size | 60 x 60 pixels |
| Co-registration with FTS | <0.3 km |
| Noise | <0.5 K at 230 K |

Mission Lifetime: 4 years

# Proposed orbital configuration




817 km polar sun-synch orbit in convoy with MetOp-SG to allow:

- cross-calibration
- full infrared spectral coverage
- combined retrievals
- assessment of retrieval improvement cf single instrument

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# Schedule

**Overall Programme Logistics**

- E2E simulator being built
- Planned ground and flight campaigns autumn 2018/spring 2019
- Down selection to 1 mission scheduled for summer/autumn 2019
- Nominal launch date: 2025

**Interested in getting involved?**

$1^{st}$ FORUM Workshop, Florence 23-$25^{th}$ October
see: http://fts.fi.ino.it/forum/workshop/

- Abstract submission open to $17^{th}$ September
- Registration open to $5^{h}$ October

# Any Questions?

forum
Far-infrared-Outgoing-Radiation Understanding and Monitoring

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SECRETARIA DE ESTADO DE DEFENSA
INTA

ThalesAlenia Space
a Thales / Leonardo company

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# Retrieval Method

$$L_{aircraft}^{\uparrow} = \underbrace{\varepsilon_s B(T_s)\tau}_{\text{Surface emission transmitted to plane}} + L^{\uparrow} + \underbrace{(1-\varepsilon_s)(L_{aircraft}^{\downarrow}\tau^2 + L^{\downarrow}\tau)}_{\text{Downward atmospheric emission reflected by surface and transmitted back to plane}}$$

Measured nadir radiance

Surface emission transmitted to plane

Upward emission of atmospheric layer below plane

Downward atmospheric emission reflected by surface and transmitted back to plane

Neglecting negligible terms and considering Lambertian surface reflectance:

$$\varepsilon_\nu = \frac{L_{\nu,aircraft}^{\uparrow} - \tau_\nu L_{\nu,eff}^{\downarrow} - L_\nu^{\uparrow}}{\tau_\nu (B_\nu(T_s) - L_{\nu,eff}^{\downarrow})} \qquad (1)$$

Main challenges are:

- Accounting for atmospheric absorption and re-emission (retrievals only attempted when t > 50 %)
- Estimating surface temperature

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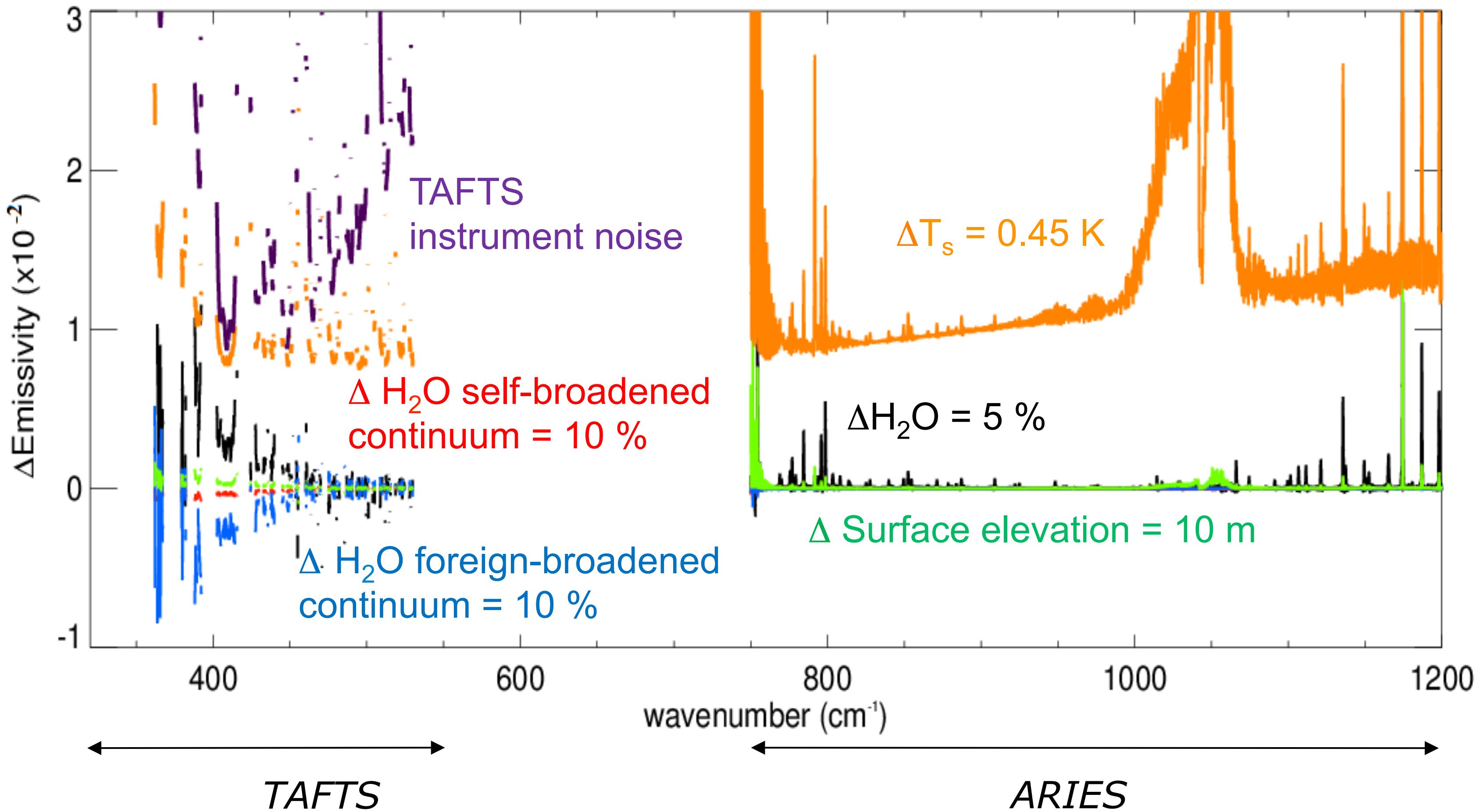
# Uncertainty Analysis




Typical combined uncertainties are of the order 0.035 (TAFTS) and 0.015 (ARIES)

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| Run | Time (UTC) | Mean altitude (m) | Effective Radius (μm) |
|---|---|---|---|
| 1 | 11:49:31-12:00:06 | 8336 | 38 ± 10 |
| 2 | 12:03:12-12:19:50 | 8018 | 25 ± 6 |
| 3 | 12:22:49-12:31:21 | 7708 | 22 ± 6 |

| Scattering database | Effective radius, $r_e$, (μm) | | | Cloud optical thickness $\tau_{355}$ | | |
|---|---|---|---|---|---|---|
| | A | B | C | A | B | C |
| GHM | 22 | 27 | 33 | 6.0 | 5.1 | 4.4 |
| ASC | 16 | 22 | 26 | 6.2 | 5.2 | 4.4 |
| SC | 21 | 28 | 27 | 5.6 | 4.8 | 4.1 |